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Influences of intelligent evacuation guidance system on crowd evacuation in building fire

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ABSTRACT

The intelligent evacuation guidance system (IEGS) is a new concept and product in China, using an intelligent inducing algorithm to get dynamic evacuation routes and improving evacuation efficiency. This paper analyzes IEGS's influences on crowd evacuation by simulating a fire scene on the experimental platform of the "black house", and some important conclusions are obtained. These conclusions including layout of exit position, settings of evacuation channel number and width, determining of installation distance and installation position mode of the intelligent acousto-optic evacuation indicator (IAEI), and choice of sound and visual inducing, can be a guidance in practical engineering and provide a reference for national standard 'fire emergency evacuation lighting indication system (EELIS)' modification.

1. Introduction

Safe crowd evacuation in fires, a complex system involving three factors (architectural structure characteristics, fire development process and human behavior) which interact with each other, is one of the hot researches of architectural science and fire safety science. In recent years, the development and utilization of large-scale, multi-functional buildings and underground space raise higher requirements for safe evacuation. Most of these buildings have as features, large areas, large room capacities, functional diversity, many combustible materials, large electricity power load, etc., and these features would lead to the result that the evacuation path is too long or complex, and causes evacuation time delay. Fire smoke movement in large space areas spreads quickly, especially in atrium and vertical opening spaces, which increases the fire hazard and personnel evacuation difficulty. Therefore, many scholars make studies on safety evacuation in fire. Galea ER [1] and Thompson PA [2] study the personnel behavior changes in fire from different perspectives. Song Weiguo [3,4] researches the evacuation model and carries out the simulation of the people evacuation in fire. Zhang Shuping [5] launches a questionnaire survey and analysis of crowd behavior factor effects in fire. Zhang Weili [6] has conducted the research on crowd evacuation simulation in a school dormitory fire. Cui Xihong [7] researches the crowd evacuation model in large public places. These results provide the scientific and theoretical basis for how building structure parameters, fire process structure parameters and population features make effects on safety evacuation. Zheng Xiaoping [8] analyzes the crowd jam in public buildings based on cusp-catastrophe theory. Especially, Zheng Fatai [9] puts forward the idea of intelligent acousto-optic evacuation indicator (IAEI) which could be applied in engineering for safety evacuation (IAEI is a product conforming to GB17945-2000 [10,11]). Jianyong Shi [12] proposes an agent-based evacuation model which is developed to simulate and analyze the egress progress in large public buildings. M. liu [13] uses the support vector machine (SVM) approach to study pre-evacuation human behavior in super high-rise buildings fire. Nowadays, Chinese scholars propose a new concept — intelligent evacuation guidance system (IEGS) as a guide for people to evacuate from fire, and some companies produced this kind of commercial system (including IAEI) and applied it in building engineering. However, there are no clear instructions and standards for IEGS installing. Therefore, we design the experiments to analyze the IEGS influences, and then settle on the installation distance, position and mode of IAEI which provides references for national standard 'fire emergency lighting and evacuate indicating system' modification.

2. The working principle of intelligent evacuation guidance system

Traditional evacuation system (here we take emergency evacuation lighting indication system (EELIS) as an example) consists of identification devices showing the fixed direction and safety exit sign devices. The devices are installed according to "code for fire protection design of buildings" [14] and "fire emergency lighting system" [15], as shown in Fig. 1. The safety signs are high exit signs, low dispersal indicators and ground continuous oriented indicators, and all the signs could be sound-inducing, visual-inducing, or dual-inducing (such as sound and light alarm device).

The IEGS shown in Fig. 2, is composed of a computer, the smoke detecting device, crowd evacuation speed detectors, evacuation route identification (using luminous type indicator, sound and light alarm

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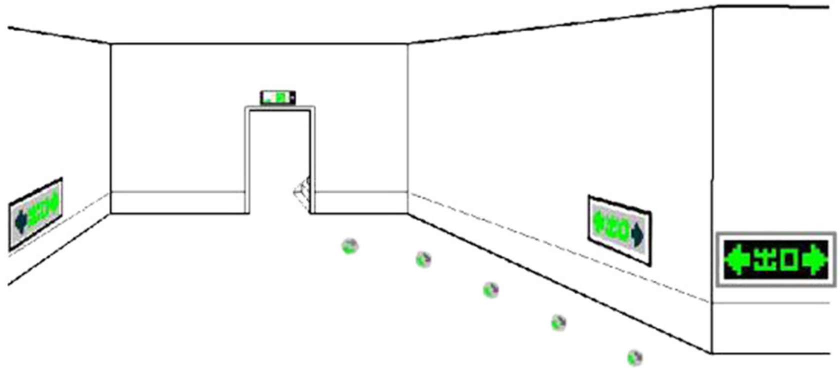

Fig. 1. Safety sign installation diagram.

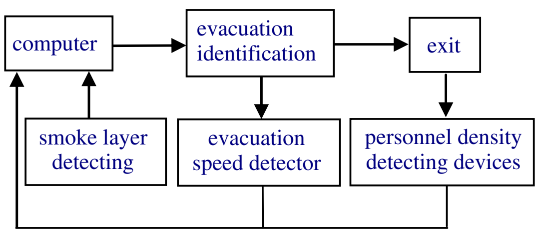

Fig. 2. The intelligent evacuation guidance system.

devices or IAEI to indicate the route) and exit signs. IEGS system uses an intelligent inducing algorithm based on multi-parameters to get dynamic evacuation routes. The smoke state parameters, human behavior parameters and construction parameters (the three kinds of parameters would influence crowd evacuation model), are input variables in the system. Control signals for safety signs are the output variables. Luminous type indicators, sound and light alarm devices or IAEI, and exit signs are all safety signs in IEGS. When the fire occurs, the system constantly optimizes the evacuation routes according to the personnel density or speed, smoke layer information, building facilities and structure, building environmental parameters, and then outputs the optimal real time dynamic evacuation routes. The dynamic evacuation routes adopt a three-point orientation principle, as shown in Fig. 3. There are three IAEIs in the same line. If the sounding order is ① → ② → ③, the evacuees are guided to the right. If the sounding order is ③ → ② → ①, the evacuees are guided to the left. The flash arrow has four kinds of shapes: ↑, ↓, ←, and →, corresponding with sounding directions, keeping on flashing while inducing sound (the flashing frequency is consistent with sound inducing cycle), which increases the visual effect.

3. Construction of experimental platform

It is the ground floor (31 × 16 × 5.5 m) of a building with three exits, A, B and C. The A, and B exits are both 2 m wide, and C is 4 m wide. The walls, top surface and ground are painted gray. A number of movable shelves are displayed in the ground floor. The width and number of channels can be adjusted by moving shelves.

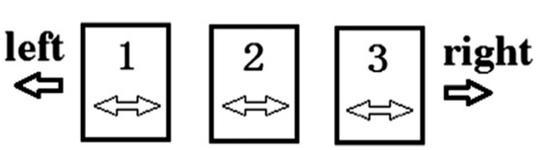

Fig. 3. Three-point orientation principle.

Fire smoke is generated by an outdoor smoke generating device through a pipeline. The smoke production is obtained by the following steps: ① Setting the fire scene: combustible wooden shelves (shelf height is 4.3 m), leather seats, sofas and other common items are as fire loads, and with these loads we can use equation $Q = 0.1876t^2$ (kw) [16,17] to design the fire scene. The ignition point is set in the middle of the black house shown in Fig. 4.② Obtaining the danger time T according to fire danger conditions by the CFAST model (danger time means the time from fire starts to the fire causes harm to people). There are three kinds of fire danger conditions which would cause harm: (a) The smoke layer height is higher than that of human eyes, and the gas temperature is 80 °C ~ 200 °C. In this situation the thermal radiation produced by smoke gas would cause unrecoverable skin burns for people. In this paper the gas temperature is set as 190 °C; (b) The smoke layer height is lower than that of human eyes, and the gas temperature is 110 °C ~ 120 °C. In this situation thermal radiation produced by smoke gas would harm the human body, here taking 115 °C as gas temperature; (c) The volume fraction of CO reaches 2.5×10^{-3}, and the toxic gas would cause harm to humans. In this paper, the human eye characteristic height is taken as 1.5 m, and the environmental temperature is 20 °C [18]. The results from the CFAST model shows that: when the fire time reaches 248 s, the thickness of the smoke layer is 4 m, and the temperature is 55 °C, which is not harmful to the people; when the fire time reaches 410 s, the smoke layer temperature is 115 °C, which can cause direct burn on human body, and at the same time the volume fraction of CO is far less than 2.5×10^{-3}, no harm to human body. Therefore, the fire danger time is set as 410 s according to the fire danger condition (b); ③ The smoke production per unit time would be obtained via the volume (31 × 16 × 5.5 m) divided by the T (410 s). Based on smoke production per unit time, smoke generating device is selected to simulate fire smoke environment.

The smoke gas concentration sensors, crowd evacuation speed detectors and camera equipments are arranged on the specified location. The cameras are installed as in Fig. 4. Smoke gas concentration sensors are distributed according to GB50016-2006 in the "Black house".

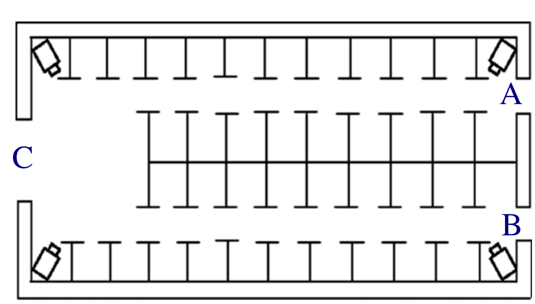

Fig. 4. Diagram of black house distribution.

Table 1
Detailed information of three groups.

Attributes	Numbers	Sex ratios	Average ages	Average heights	Max/min (ages)
Students	416	215:201	21.5	170.5 cm	23/20
Mixed crowds	400	198:202	38.4	168.4 cm	47/8
Special crowds	410	204:206	56.8	164.8 cm	71/8

Crowd evacuation speed detectors should be set on every channel, and the distance between detector and the nearest exit is 5 m.

Data collected from these equipments are as the inputs entering into data collection system and image data acquisition system by the RS485 interface. IAEI should be distributed along the channel to the exit, and the location and distance of IAEI (connecting with IEGS through control busses) could be adjusted according to the experiment requirement.

The “Black house” experimental platform is as shown in Fig. 4. The combination of smoke gas and the “black house” can better reflect the influence of people's fear, conformity of psychological factors on the evacuation [17]. Human psychology would directly affect human behaviors, and then affect the crowd evacuation model. Therefore, a more accurate analysis of the interaction mechanism between IEGS and crowd evacuation model can be obtained.

There are three kinds of crowd evacuation models based on people's familiarity with the building environment: shortest path behavior model, backtracking model and herd behavior model. The shortest path behavior model is assuming that evacuees are completely familiar with the orientation and position of exits, and in this model evacuees could go towards the nearest exit. The backtracking model is assuming that evacuees are not very familiar with the surrounding environment, and in this model evacuees only go back with the same way they get in. The herd behavior model is assuming that evacuees are strangers to the surrounding environment. When it is in emergency decision-making process, individuals in a group would evacuate together without planned direction in the herd behavior model.

In order to get a valuable result, fire evacuation experiments with different crowds have been conducted. These crowds are the student crowd, mixed crowd (school staff, students and families) and special crowd (the aged, young people and children). Detailed information on the three groups is shown in Table 1. The experiment results of three crowds are similar. Therefore, we only use student crowd evacuation as an example to illustrate the whole process in this paper. Under normal lighting conditions, 416 students (personnel density is set as 0.85 person/m^2 according to GB50098-2009 [19]) are grouped entering the “black house” through different doors. The test is started from normal lights off, terminated on the time the last student is getting out of safety exit, counting the student number every 50 s. The strategy that students are grouped entering “black house” through different doors is to further observe the coupling mechanism of crowd evacuation models and IEGS, and also to help to improve dynamic identification algorithm of IEGS.

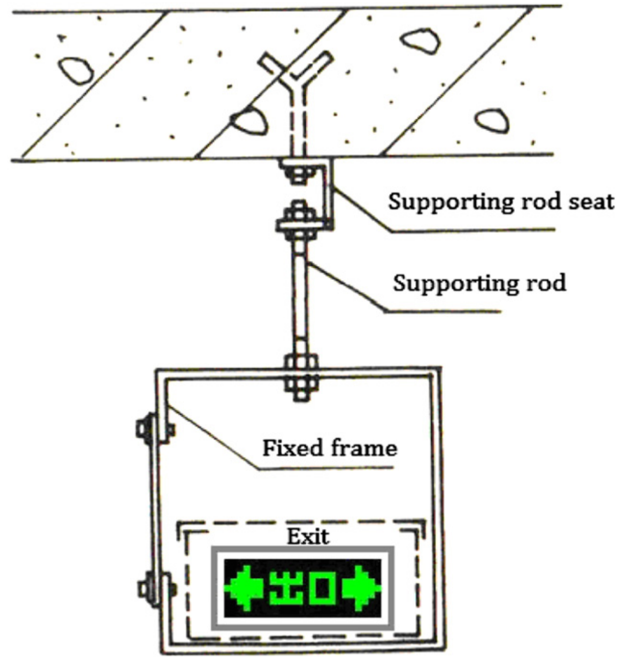

Fig. 6. The space suspension mode.

4. Results and discussions

4.1. Exit position effects on evacuation behavior

The relationship between the exit position and evacuation channel, and human evacuation situation are shown in Fig. 5 (a, b, c, d). The

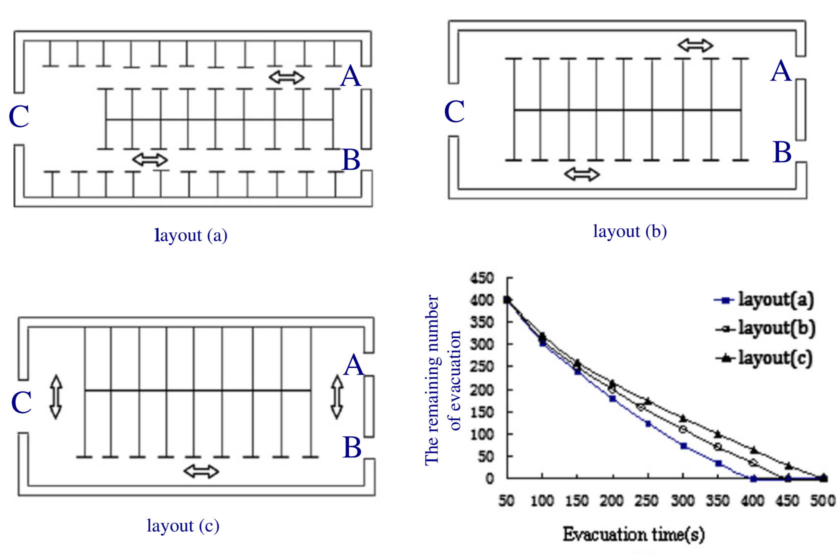

Fig. 5. The exit location influences on crowd evacuation.

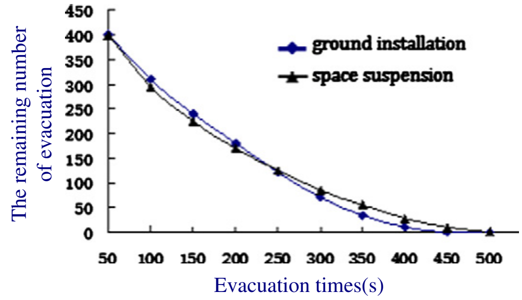

Fig. 7. The safety indicator position influence on crowd evacuation when distance is 10 m.

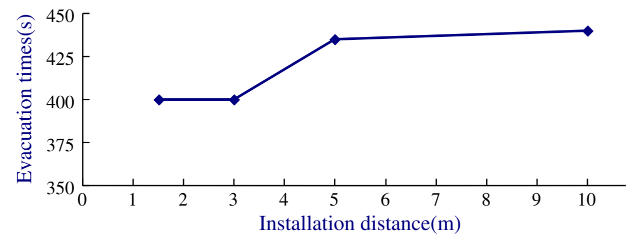

Fig. 9. Safety indicator distance influences on crowd evacuation time.

relationship between the exit position and evacuation channel is divided into: ① the exit position faces the evacuation channel (a); ② the surrounding channel and the channel forms a certain corner to the exit (b); and ③ the channel is three sides around and forms a certain corner to the exit (c). The effects of safety exit location on the personnel safety evacuation under three kinds of circumstances are shown in Fig. 5 (d). From Fig. 5 (d) we can see that evacuation in the situation of the exit position facing the evacuation channel (a) takes the shortest evacuation time. Changing the location and quantity of shelves to adjust the width of the evacuation channel also affects the crowd evacuation. The experimental results show that increasing the evacuation channel number and width can improve the evacuation efficiency. When the evacuation width is 6 m, the number of channels are 1 (6 m wide), 2 (respectively 3 m wide) and 3 (respectively 2 m wide), and per capita evacuation time are 6 (s), 4.5 (s) and 3.2 (s). As the evacuation efficiency refers to the length of the per capita evacuation time, obviously, the per capita evacuation time is smaller, the evacuation efficiency is higher. The results are consistent with the Zhu Kongjin [20] simulation results.

4.2. The effect of safety indicator position and distance on crowd evacuation behavior

IAEI has two installation position modes: the ground installation mode (IAEI is installed on the ground, as shown in Fig. 1) and the space suspension mode (IAEI is installed on the ceiling, 2.2 ~ 2.5 m from the ground, as shown in Fig. 6).

The installation distances of IAEIs are respectively 1.5 m, 3 m, 5 m and 10 m as shown in Fig. 1. To save space, here we only give the evacuation results when the installation distances are 3 m and 10 m, as shown in Figs. 7 and 8. From the two figures, it can be seen that: ① When the installation distance is constant, the space suspension mode has better performance for crowd evacuation if it is at good visibility at the smoke fire initial stage (within 250 s as shown in Fig. 7, and within 200 s as shown in Fig. 8.), and if smoke concentration increases and the visibility worsens, the ground installation mode evacuation has better performance; and ② when the installation position mode is constant, the installation distance change in space suspension mode has less effects on crowd evacuation than it has in the ground installation model. Fig. 9 shows the installation distance influence on evacuation time, and it can be seen that in either ground installation or space suspension modes, installation distance shortening leads to shorter evacuation time, and the evacuation time is shortest when the distance is less than 3 m. Based on the analysis above, the ground installation mode and the space suspension mode should be used together in practical engineering, and the installation distance should be reasonable. If the space suspension mode focuses on the fire initial stage, distance could be relaxed to 10 m. If the ground installation mode focuses on the smoke fire later period, the distance should be limited within 3 m.

4.3. Acousto-optic inducing effect on evacuation

The sound-inducing, visual-inducing and acousto-optic inducing (dual-inducing) are analyzed when the installation distances of IAEIs are respectively 1.5 m, 3 m, 5 m and 10 m. This paper takes the ground installation as an example to illustrate the results of the experiment. The evacuation results by sound-inducing are as shown in Fig. 10, and the evacuation results by visual-inducing are as shown in Fig. 11. Fig. 10 shows that the installation distance change has a little effect on the sound-inducing of evacuation (The slope of the curve has a relatively small change), so the installation distance can be set as 5 ~ 10 m, and that distance decrease has a little effect on shortening the evacuation time. Fig. 11 shows that the installation distance change has a big effect on the visual-inducing of evacuation (The slope of the curve has a relatively large change), so the installation distance can be set as 3 m. Comparing Figs. 10 and 11 we can see that: ① when the installation distance is 5 m or 10 m, sound-inducing and visual-inducing have similar effects on evacuation at the initial fire stage (Fig. 10 within 250 s, Fig. 11 within 200 s); and ② when the installation distance is within 3 m, the visual-inducing has better effects than sound-inducing at the later fire stage. Based on the analysis above, the sound-inducing should be combined with the visual-inducing according to the building's environmental parameters to form a reasonable acousto-optic inducing mechanism in practical engineering.

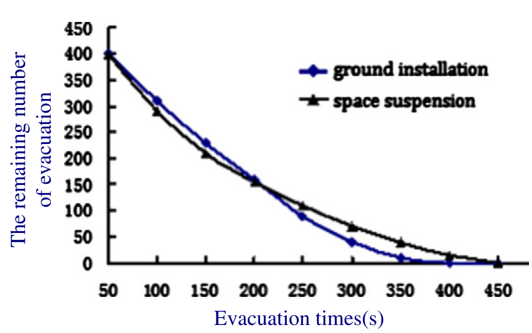

Fig. 8. The safety indicator position influence on crowd evacuation when distance is 3 m.

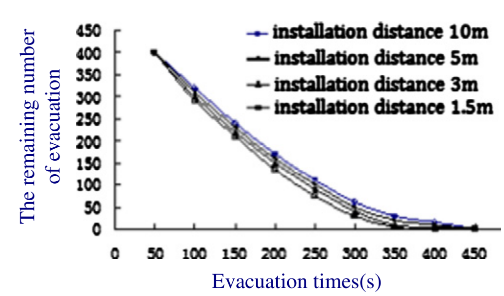

Fig. 10. The results of crowd evacuation by sound inducing.

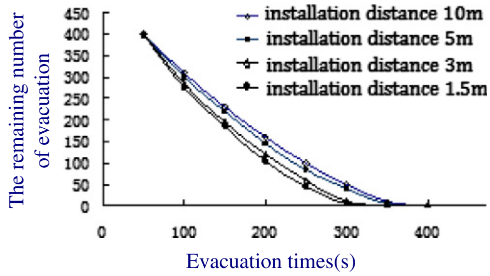

Fig. 11. The results of crowd evacuation by visual inducing.

5. Conclusion

The influences of IEGS on crowd evacuation are analyzed by simulating a fire scene on the "black house" experimental platform in this paper. The conclusions are as follows: ① The safety exit which faces the evacuation channel has the highest utilization rate on crowd evacuation. ② The increase of the evacuation channel number and width can improve the evacuation efficiency, and when evacuation channel width is constant, the evacuation channel number increase leads to higher evacuation efficiency. ③ When the installation distance is constant, the space suspension mode has better performance for crowd evacuation if it is at good visibility at the smoke fire initial stage, and if the smoke concentration increases and the visibility worsens, the ground installation mode evacuation has better performance; When the installation position is constant, the installation distance of the space suspension mode has less effect on crowd evacuation than ground installation model; installation distance shortening leads to shorter evacuation time in either ground installation or space suspension mode. ④ Comparing visual-inducing with sound-inducing, they have similar performances when the installation distance is 5 m or 10 m, but the visual-inducing leads to higher evacuation efficiency than sound-inducing when the installation distance is within 3 m. Therefore, we can see that in practical engineering, the layout of the exit position, evacuation channel number and width should be considered; the ground installation mode and the space suspension mode should be used together; the installation distance should be reasonable; and the sound-inducing should be combined with visual-inducing according to the building's environmental parameters to form a reasonable acousto-optic inducing mechanism. This study is expected to provide a reference for national standard 'fire emergency lighting and evacuate indicating system' modification.

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